THRILL

TECHNOLOGY FOR HIGH-REPETITION-RATE INTENSE LASER LABORATORIES

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European XFEL | FAIR | Laserlab Europe | LULI – From atoms to stars (Radiation, Particles, Plasmas, Fusion, Astrophysics, Planetology) | MBI

GSI | University of Rochester | HZDR Helmholtz Zentrum Dresden Rossendorf | eli | Amplitude

Funded by the European Union

THE TREND IN HIGH-ENERGY LASER DEVELOPMENTS INCREASES THE REQUIREMENTS FOR BEAM CONTROLS

T H R I L L

- The THRILL project federates the forces from 7 European research laboratories + 1 US research lab. + 1 company to make advances in high-energy laser technology.
- THRILL focuses on hardware development backed up by a field analysis about the needs of the community
  - New kilojoule-class large-aperture amplifiers are developed
  - Capabilities for large optics coating and characterization are brought online
- The trend shows that beam quality is a central concern, which benefits from current developments in hard- and software.

THE THRILL PROJECT

- Summary:

Bringing high-energy high-repetition-rate (HEHRR) lasers to the next level

- **Goal:** Conceptual design for lasers at Eu-XFEL and FAIR
- **How to get there?**
  - identify laser needs of user community (Eu-XFEL, FAIR)
  - study and development of bottleneck technologies
    - actively-cooled kilojoule-class amplifiers
    - beam transport and beam quality
    - laser architecture – simulation tools
    - optical components – large surface area coatings

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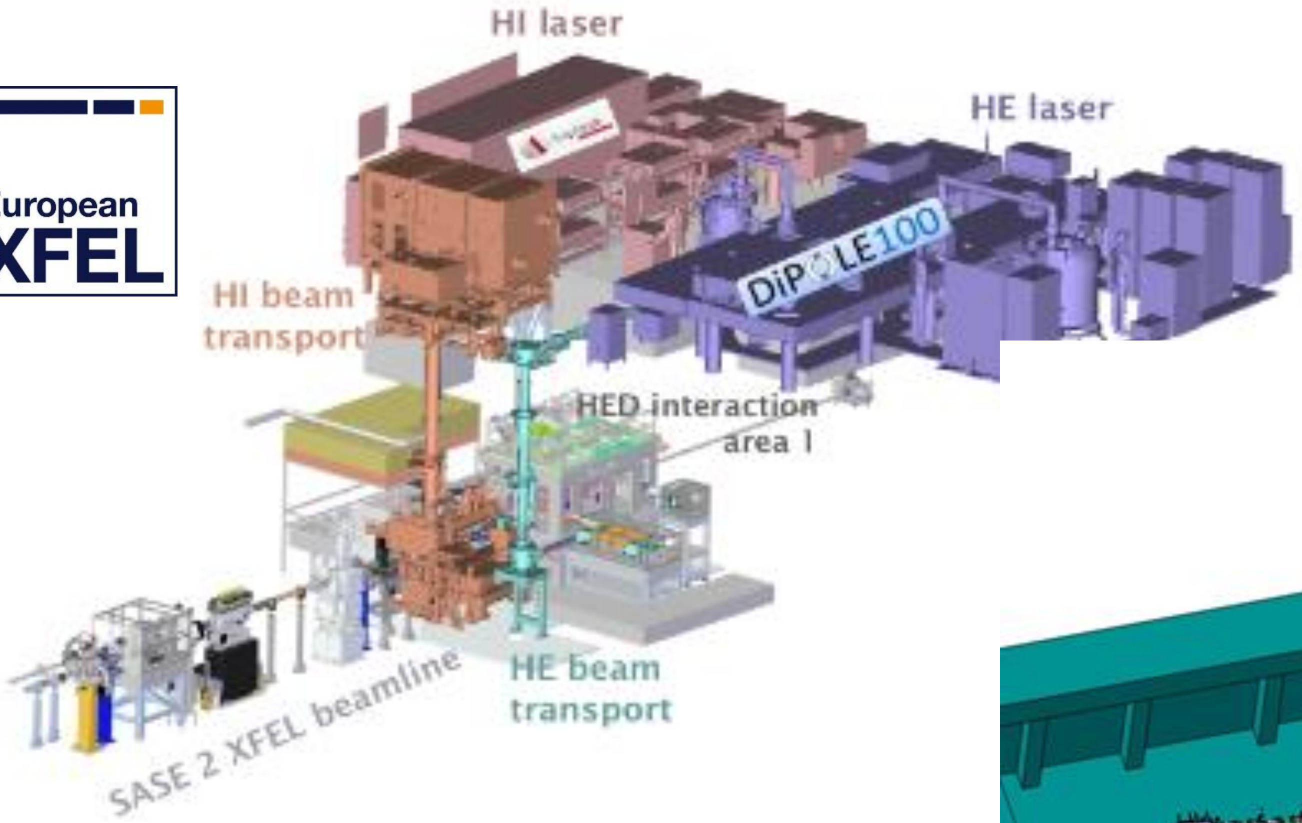
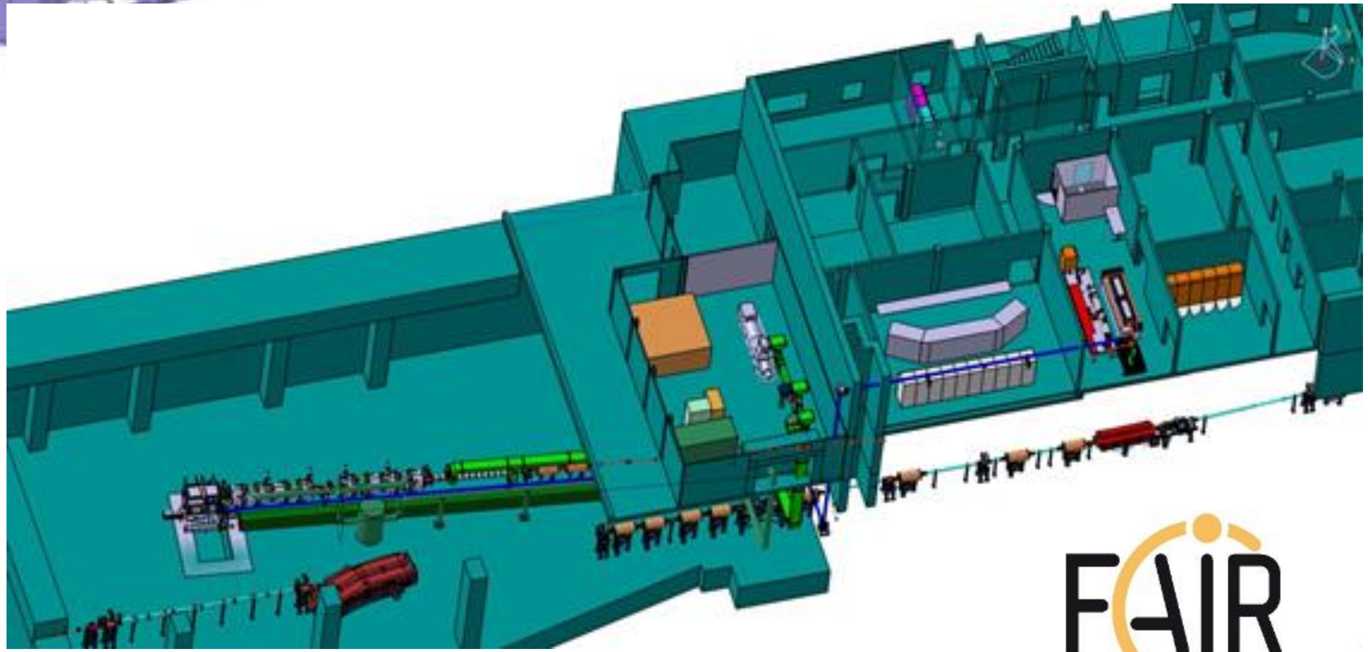
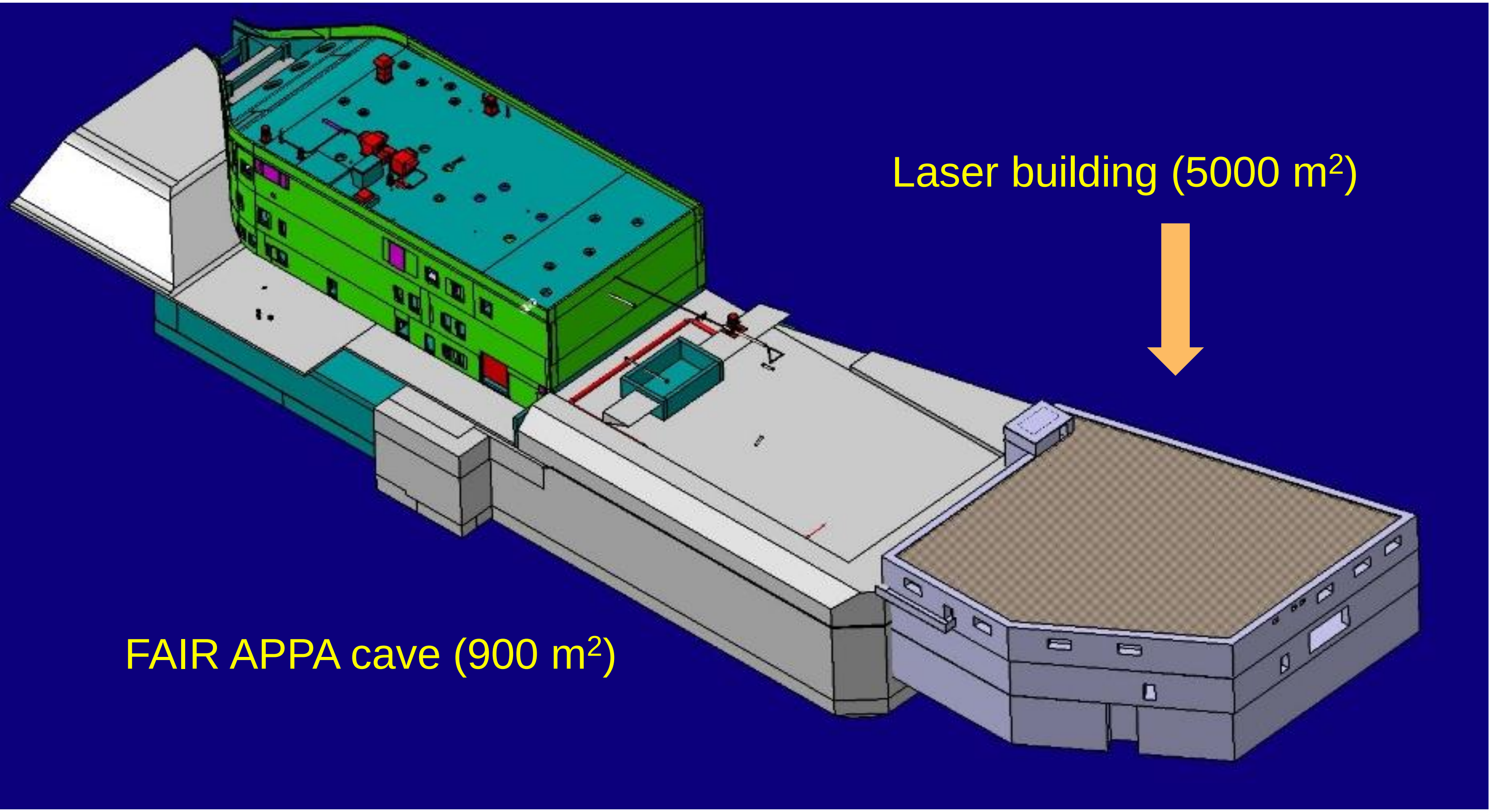
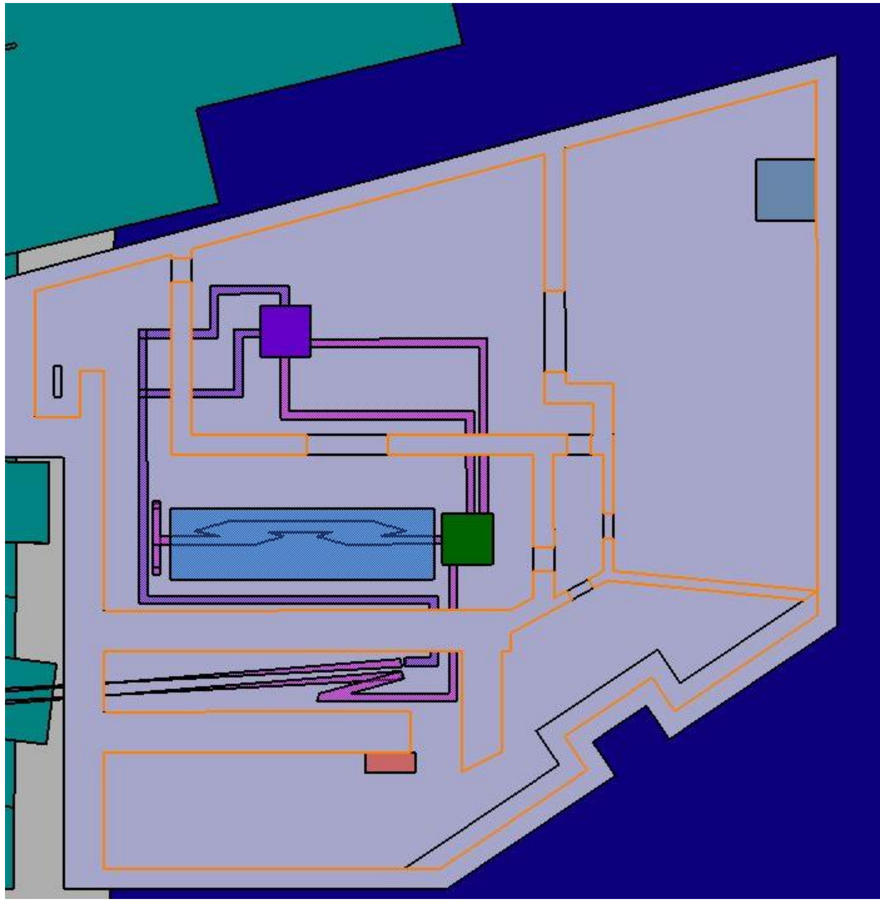
THRILL – BLUE PRINTS FOR LASER AT FAIR AND EU-XFEL





CURRENT PROPOSAL AT FAIR





THRILL´S TECHNICAL PROJECT STRUCTURE

Technical tasks and research sujects	Partners
High-repetition-rate high-energy amplification	GSI / ELI-BL / Amplitude
Beam transport and beam quality	Apollon/GSI/HZDR
Optics for high-energy lasers	ELI-BL / UoR / HZDR

↓

Advanced laser architecture for HEHRR lasers	GSI / HZDR /FAIR/ Eu-XFEL

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EXPRESSED NEED OF THE COMMUNITY

October 24-27th, 2023
Kloster Engelthal,
Ingelheim, Germany

THRILL END-USER WORKSHOP

- What are high-power lasers used for in the field (drivers, diagnostics)?
- Laser parameter range available and which are the limitations imposed by these?
- What laser parameters would be desirable and would these make new physics accessible?
- What of these wishes are realistic at all and in particular within THRILL?

→ Large interest in kJ, long (ns) pulses (WDM, dynamic compression). High-energy short pulse: high-field QED, nuclear photonics. Both: IFE, magnetic field generation, laboratory astrophysics

→ Higher repetition rate: 1 shot/minute (5 minutes) already “game changer”

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Deliverable status	
Submitting author	V. Bagnoud, Zs. Major
Verified (WP leader)	Zs. Major, D. Kraus (end-user board)
Approved (Coordinator)	V. Bagnoud
Due date of deliverable	31.12.2023

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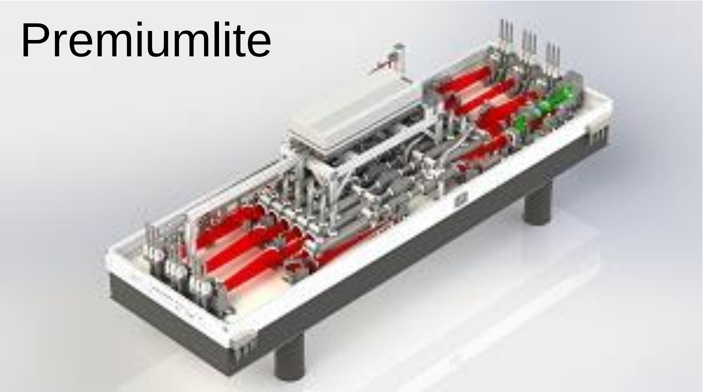
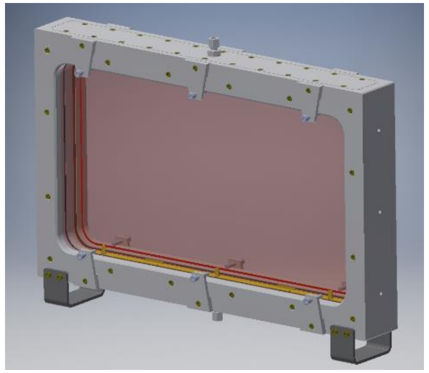
THRILL TECHNICAL WP: HIGH-REPETITION-RATE HIGH-ENERGY AMPLIFICATION

Goal: investigate, optimize, and compare different approaches for high-average-power high-energy amplifiers in order to make the best technological choice

L4 ATON system (ELI-BL)



Pseudo-Active Mirror Disk Amplifier (Amplitude)

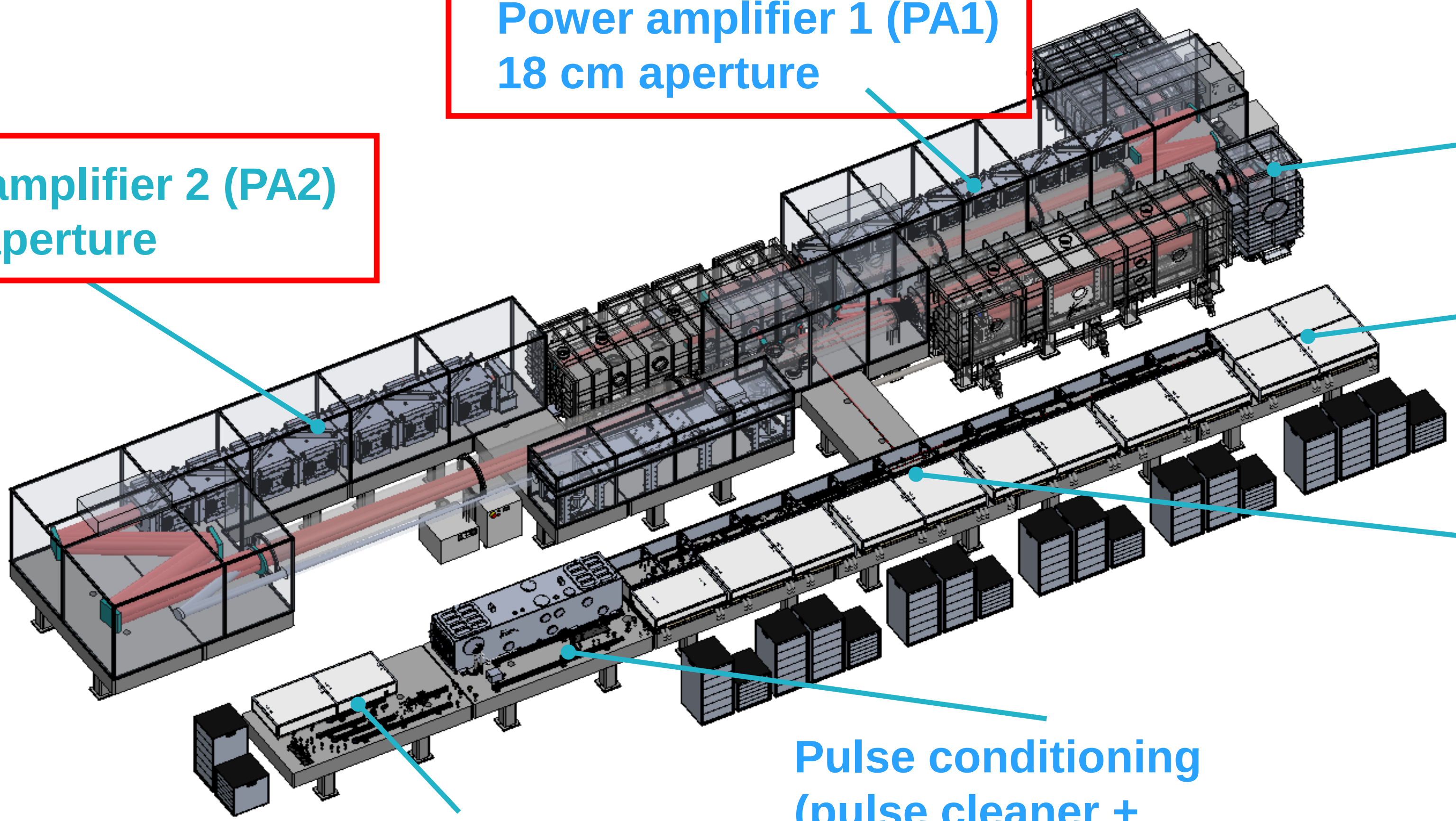


liquid-cooled glass module

water-cooled flash-lamp panel

Other large-aperture amplifier concepts (GSI)

L4-ATON LASER AT ELI-BL



ATON FEATURES LARGE APERTURE ACTIVELY COOLED GLASS AMPLIFIERS

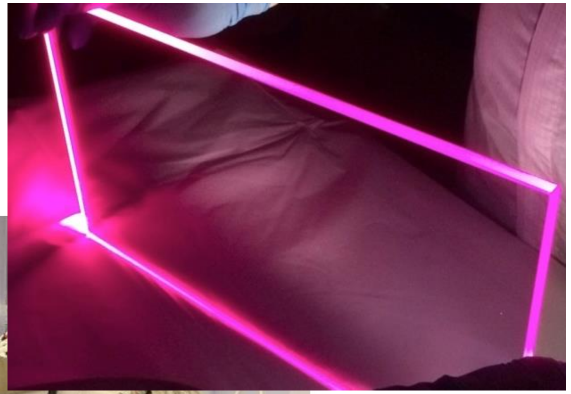
THRILL

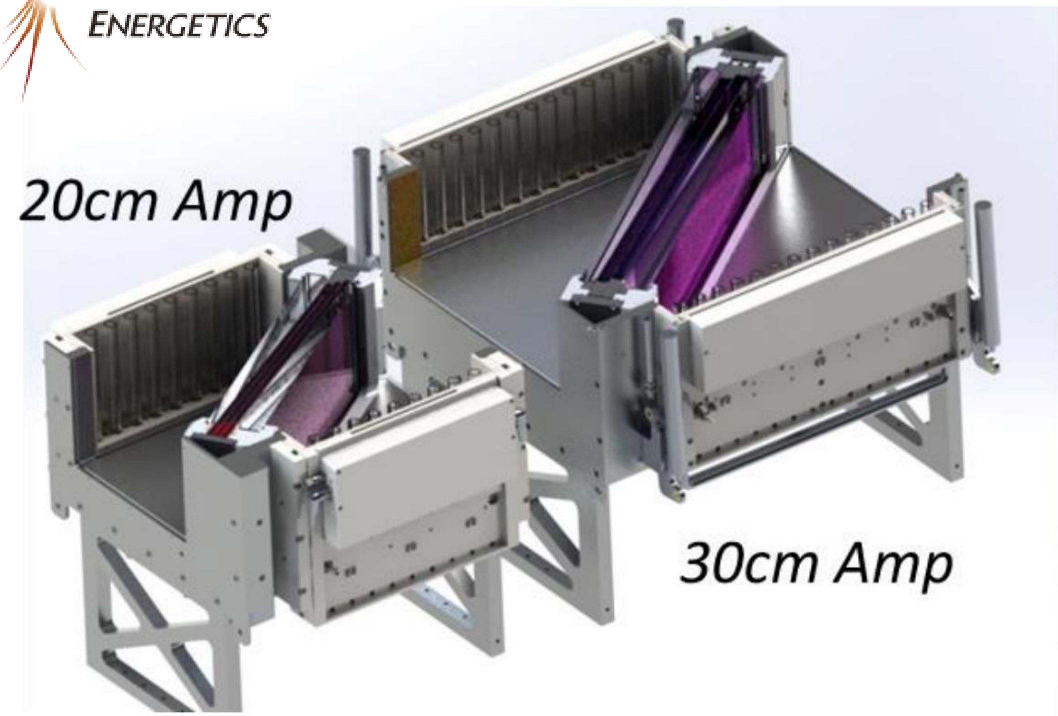
eli

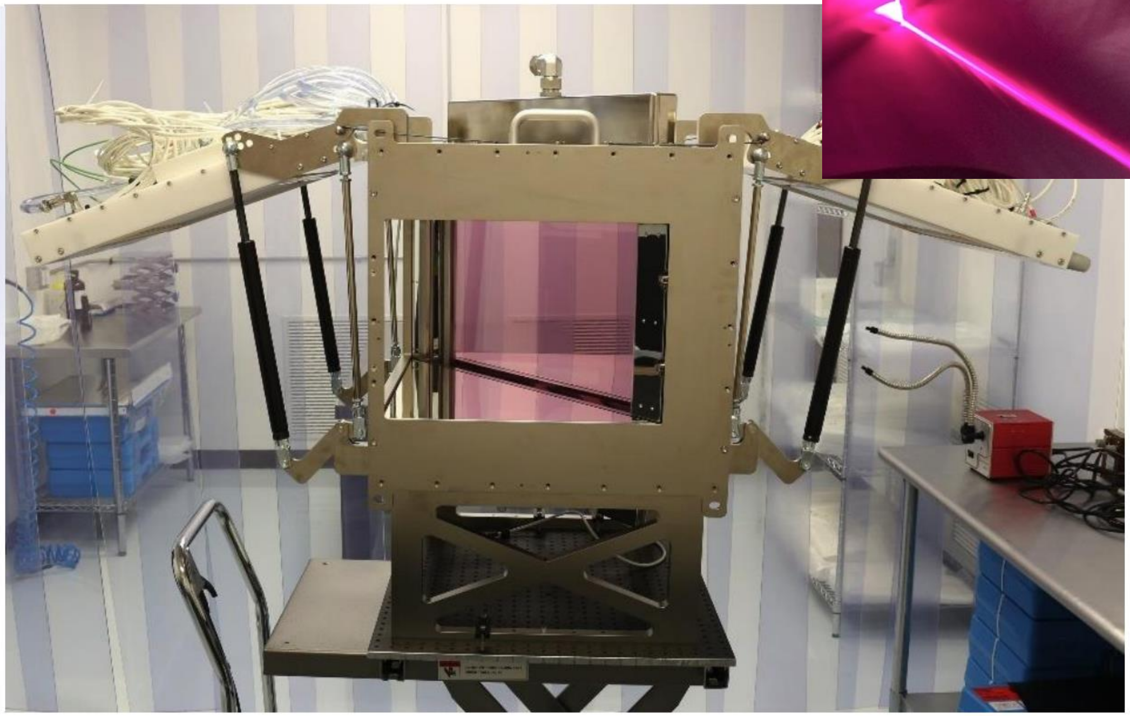
NATIONAL ENERGETICS

7 liquid cooled amplifier modules with 30 cm aperture operating up to 1/min repetition rate

Phosphate Nd:glass slab





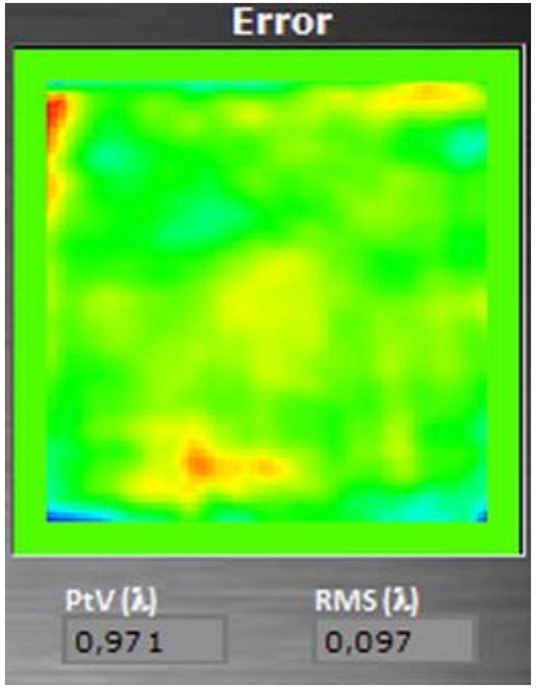


RECENT EFFORTS IMPROVED THE BEAM QUALITY

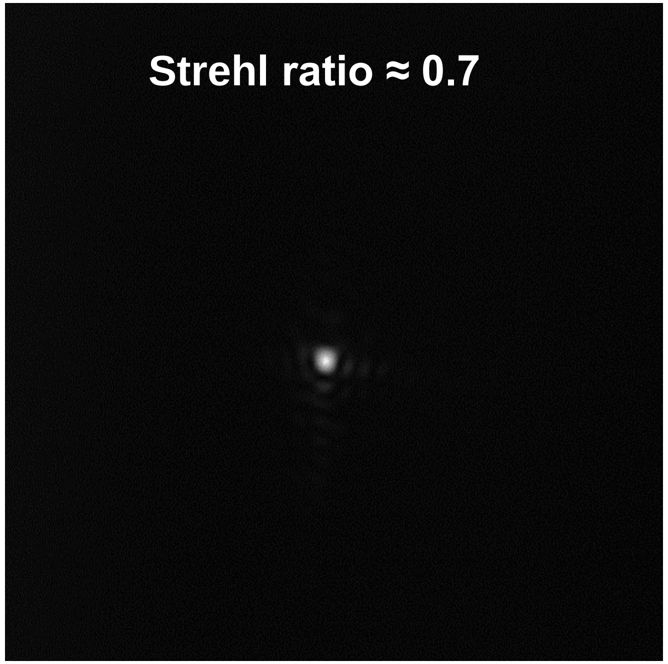
Commissioning of the beamline with full aperture beam

- Full-sized beam ~ 220X220 mm in the amplifier
- Wavefront error after DFM upgrade (82 actuators and flatter membrane)
  - up to **λ/20 in cold state**; **λ/10 in hot state** with full thermal load in the amplifier

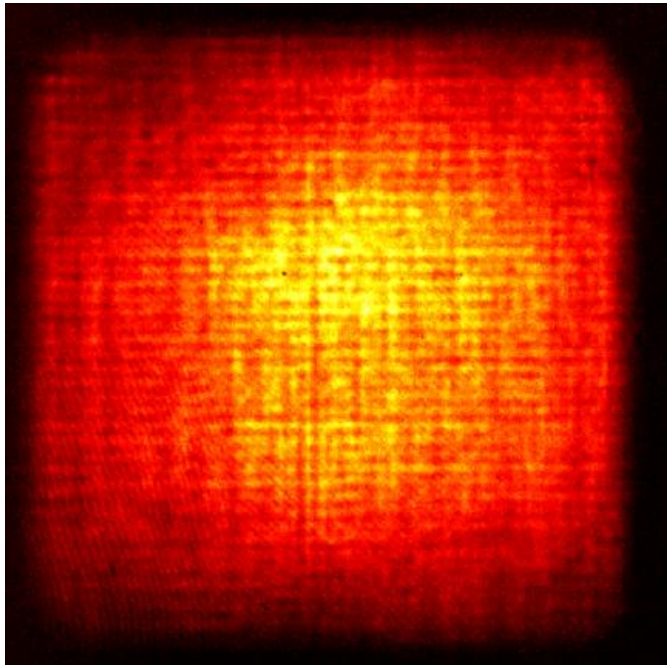
On shot Wavefront



on-shot FF



Sample NF



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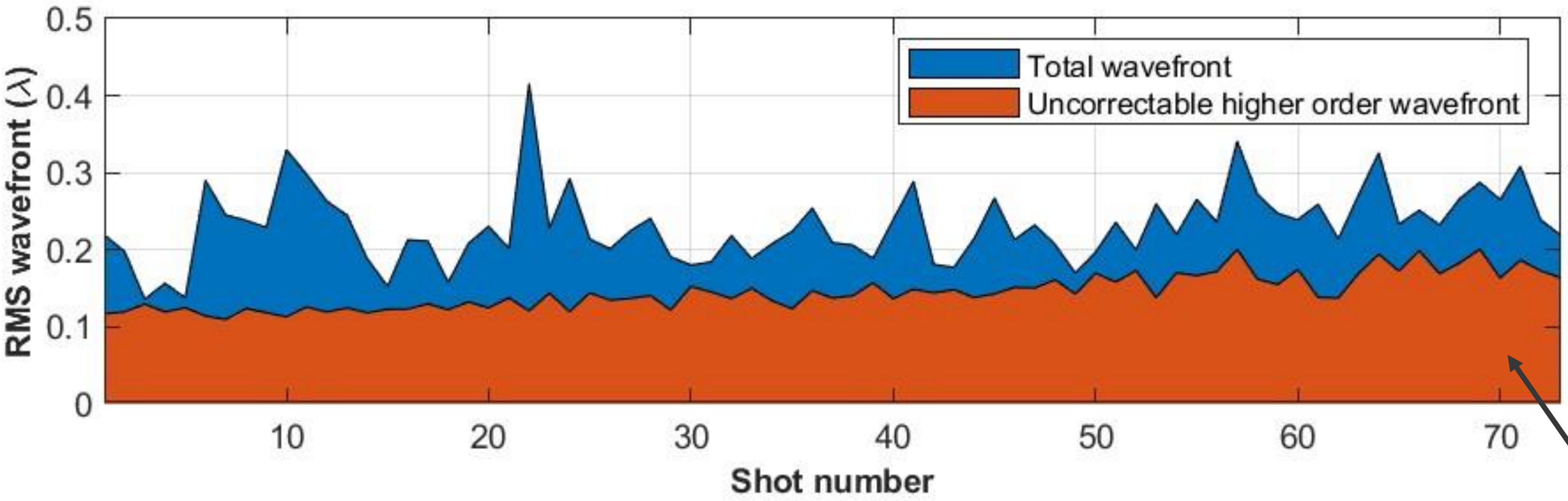
WAVEFRONT MEASUREMENTS SHOW RESIDUAL UNCORRECTED EFFECTS

- Measured without active pressure stabilization (helps to suppress fluctuations)
- Active wavefront correction from first shot (no precompensation)

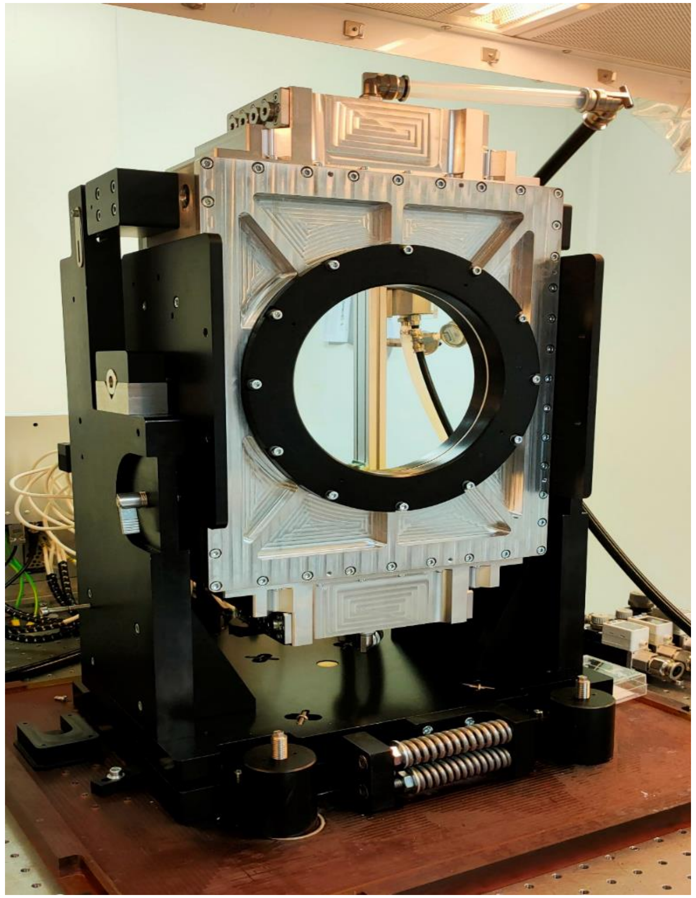


Beam fluctuations

Legendres of 6th order and higher

Higher order phase is slowly increasing at 1/min rep. rate

KJ-CLASS LIQUID-COOLED AMPLIFIER BY AMPLITUDE



The AMPLITUDE proprietary Technology: the LC-PAMDAM*

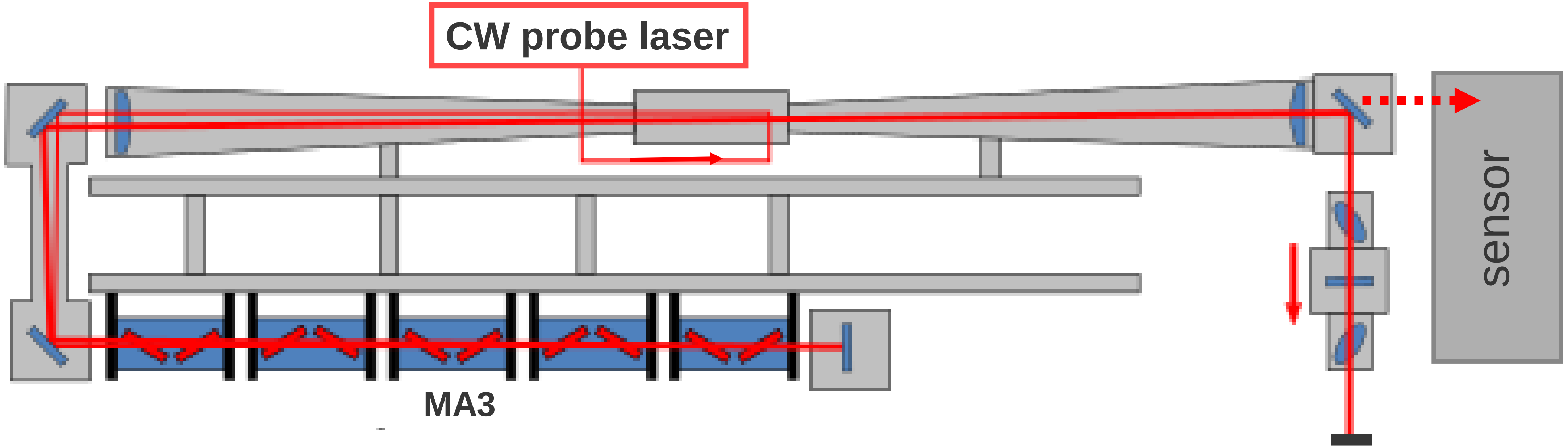
- Designed to deliver > 150J @ 1053nm (Nd:glass-phosphate) at up to **0.1Hz**.
- **Up to 6 modules implemented in a kJ-class laser operating at up to 0.1 Hz**.
- **The cooling scheme has been validated to enable > 3kJ -10Hz operation for Inertial Confinement Fusion (ICF)** in a near future.

Current status of the R&D:

- **A > 150J module assembled in summer 2024 and tested during several months in fall 2024**
- **Full characterization until summer 2025**

LC-PAMDAM* : Liquid-Cooled Pseudo-Active Mirror multi-Discs Amplifier Module

CHARACTERIZATION OF COOLING DYNAMICS OF A 315-MM GLASS AMPLIFIER



- Single amplifier (MA3) shot and thermal relaxation measured with CW probe laser and Shack-Hartmann sensor

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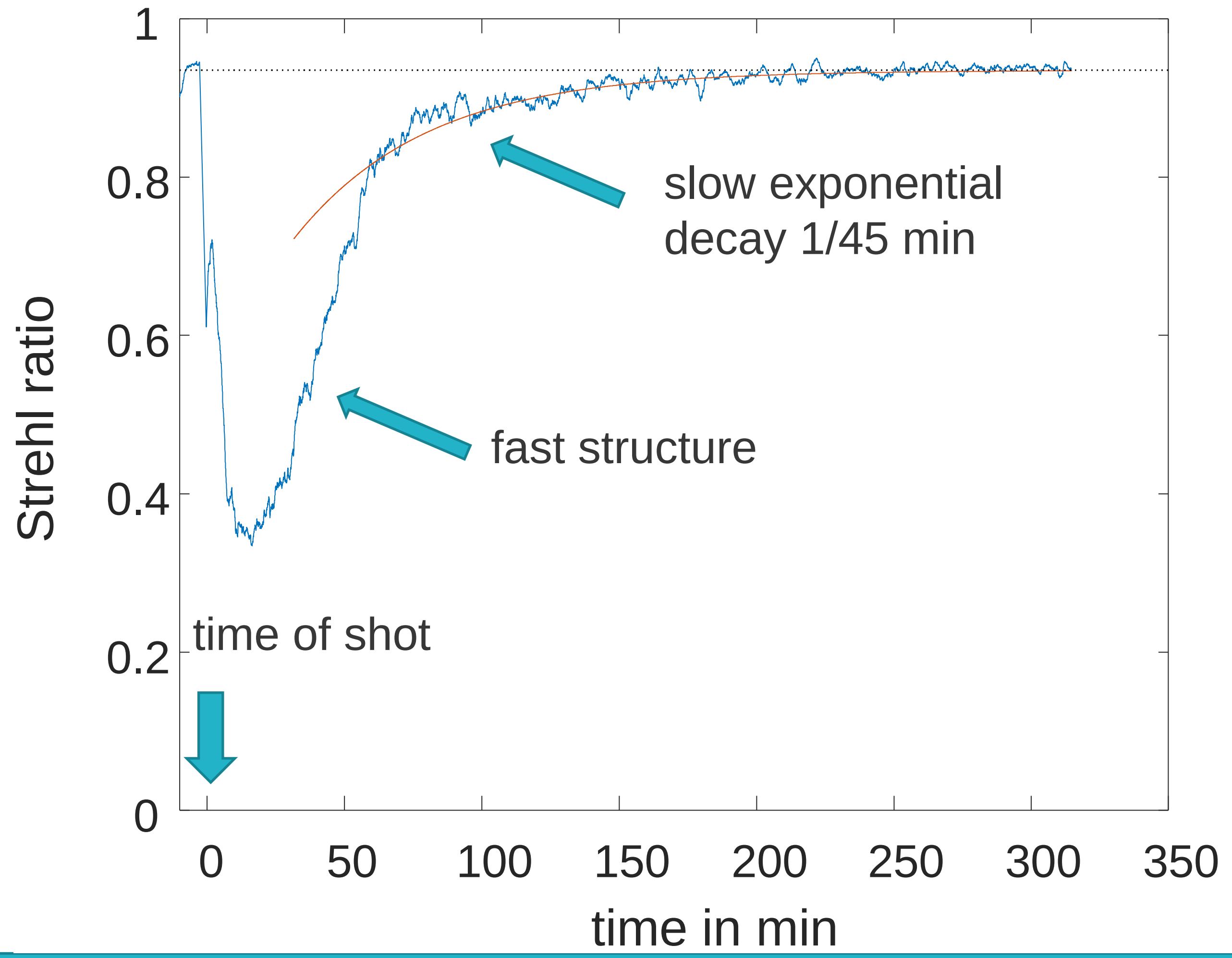
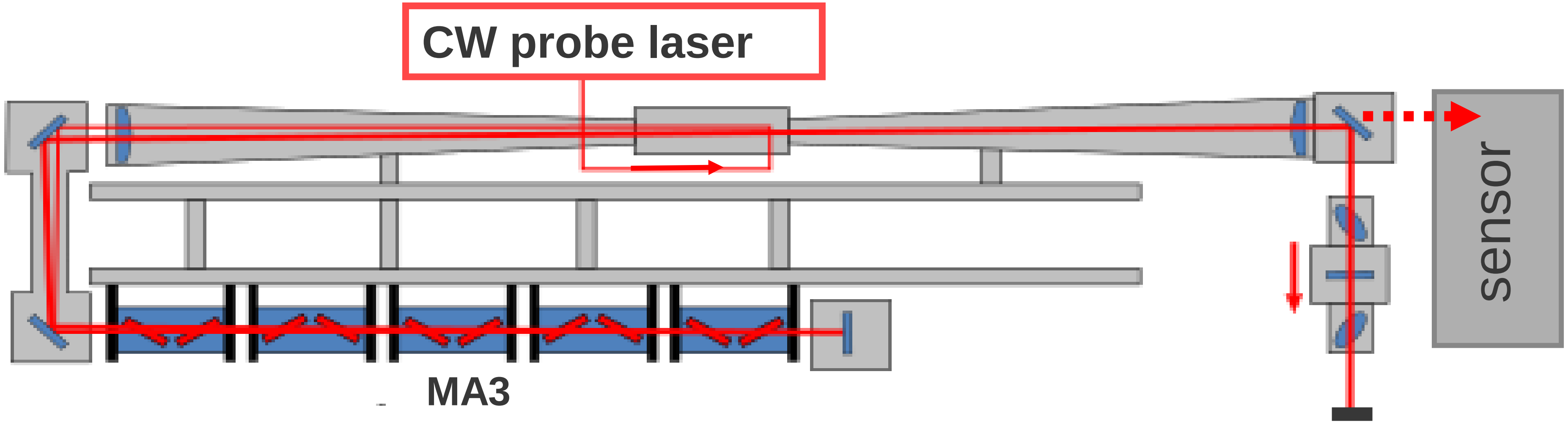
CHARACTERIZATION OF COOLING DYNAMICS OF A 315-MM GLASS AMPLIFIER

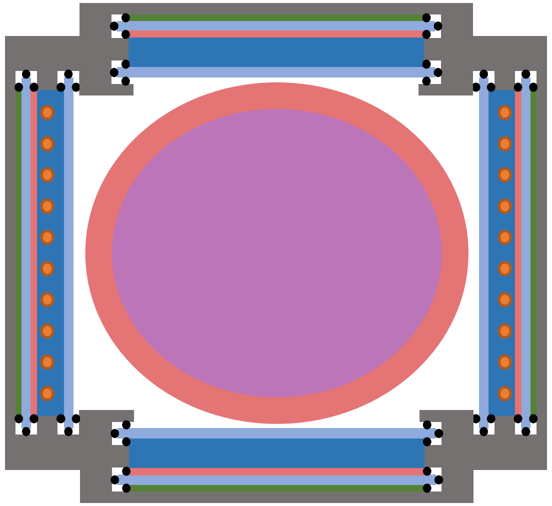


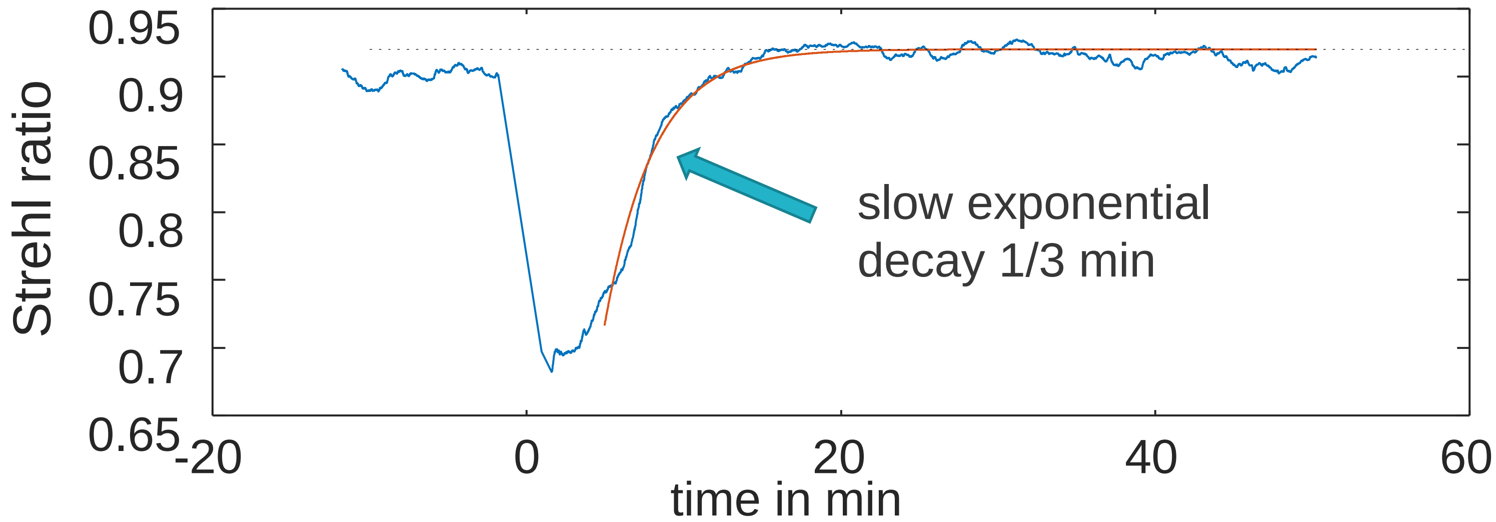
- strong perturbation appears minutes after the shot and lasts ~60 min
- slow structure with 3.5 hours decay time
- similar behavior with and without amplification medium!

CHARACTERIZATION OF COOLING DYNAMICS OF A 315-MM GLASS AMPLIFIER



cooled flash lamp module (section)

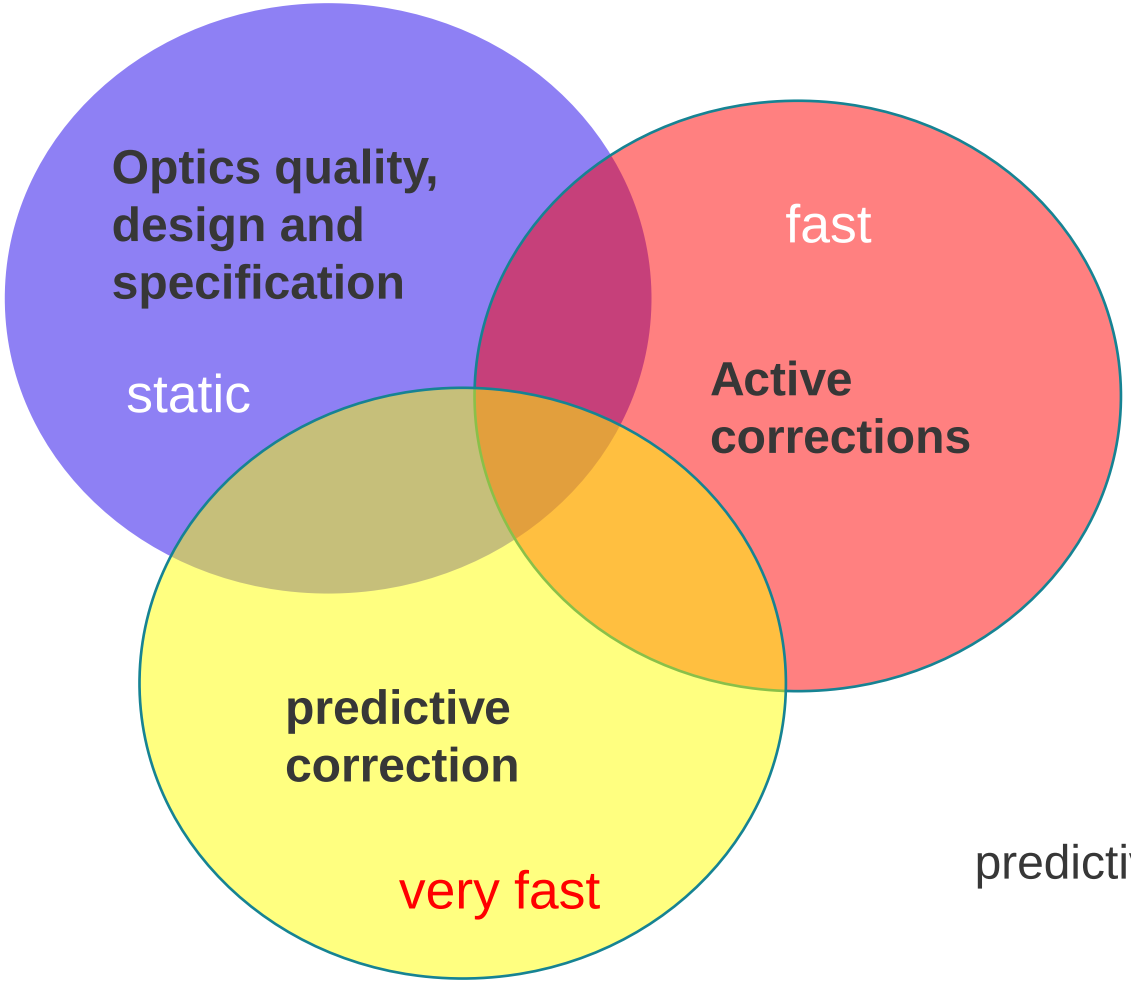


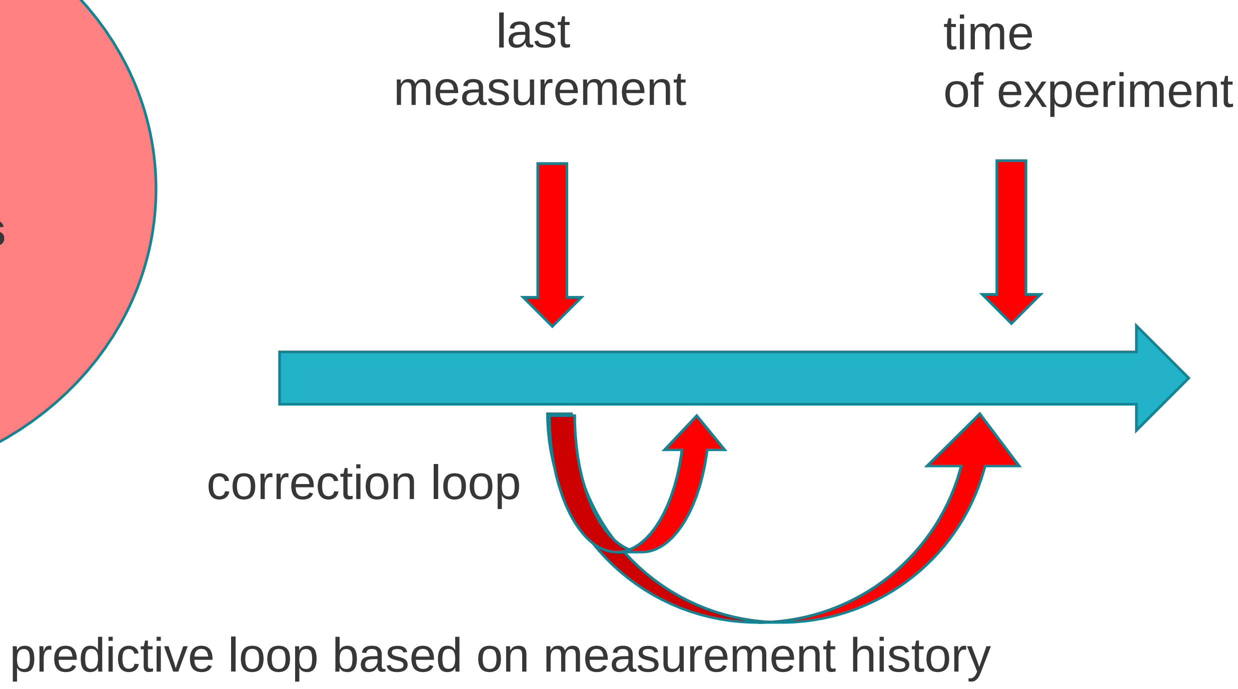


THE MAIN DRAWBACK OF THE COOLING STRATEGIES IS A BEAM QUALITY DEGRADATION

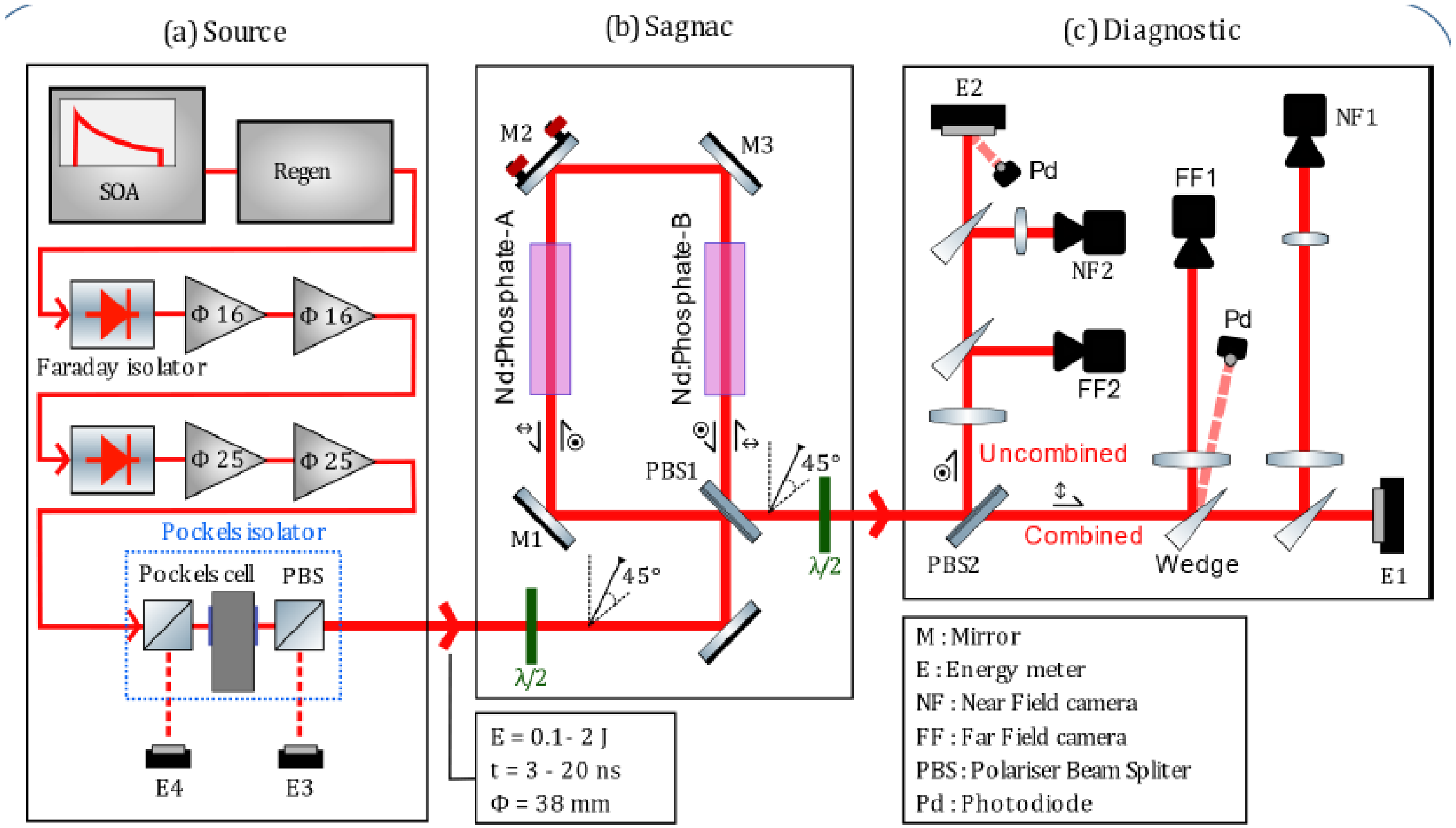
- Static aberration increases as $\sqrt{\text{number of optics}}$
- Static aberration increases because of degradation introduced by the cooling concepts (e.g. surface bending by hydrostatic pressure)
- Dynamic distortion is introduced by the high-repetition-rate operation
  - Cooling fluid dynamics introduce beam fluctuations
  - Thermal gradients are present (operation under thermal loading)
  - Vibrations by active elements (e.g. pumps)

STRATEGIES FOR BEAM CONTROL





REACHING HIGH-ENERGY THROUGH BEAM COMBINING

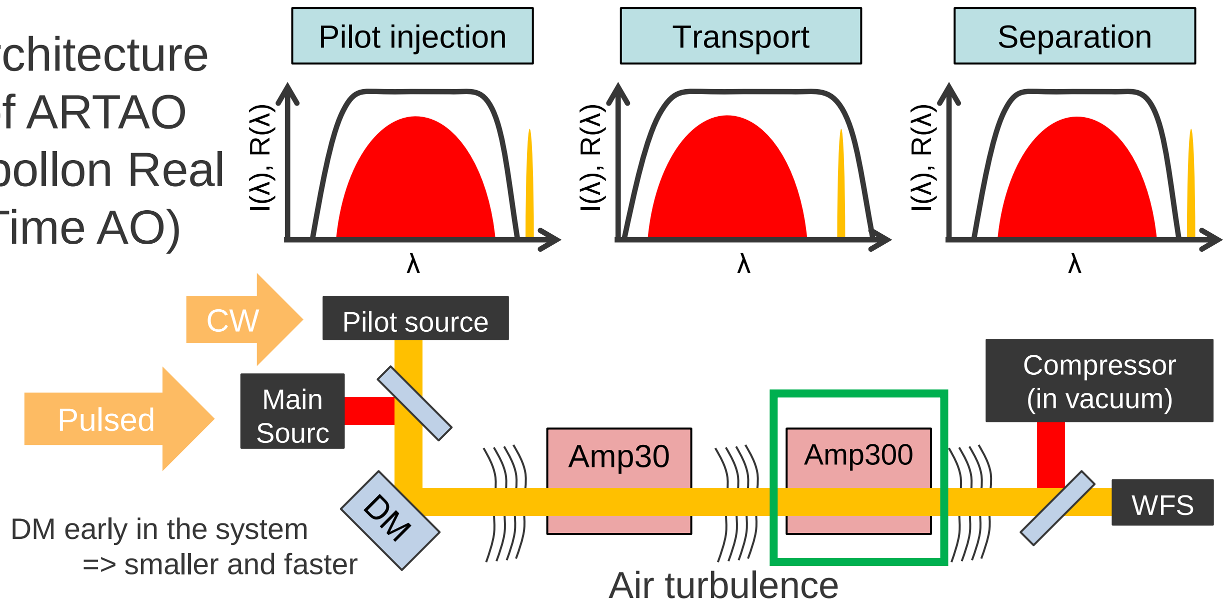


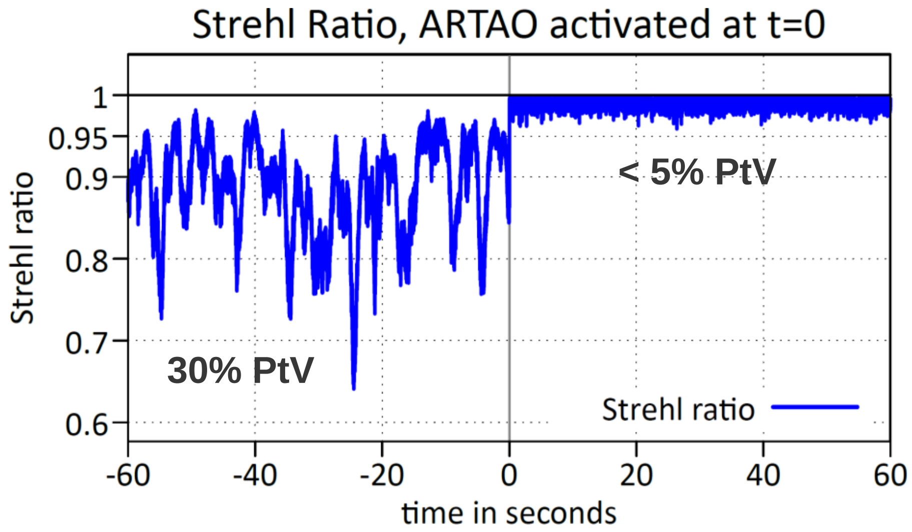
- Demonstration of beam combining with 92% efficiency at 20 J level

see talk by P. Lebegue

REAL-TIME ADAPTIVE OPTICS (AO)

Architecture of ARTAO (Apollon Real Time AO)





- Successful demonstration of 1.2 kHz RTAO at Apollon
- Short-term performance: Strehl PtV from 30% to 5%
  - ➢ next step: integration in control system and commissioning

see talk by D. Papadopoulos

TRENDS IN BEAM CONTROL

- Concepts for beam control more and more decoupled from specific hardware
  - move from hardware-specific solution to system-wide correction
- Beam control automation is inherently part of the control and supervision system
- Beam evolution prediction and pre-correction based on the history of the beam fluctuation have a good chance to improve beam stability even more

THRILL WORKSHOP (THURSDAY)

- Goal of the workshop: make a snapshot on beam stabilization techniques.
- Thursday morning sessions in parallel with the LASY tutorial.
- Thursday afternoon (mix of invited and contributed talks)

Thursday 16/01	session types
09:00 - 09:30	Parallel session 1 Contributed talks
11:00 - 12:30	Parallel session 2 Contributed talks
14:00 - 15:30	Plenary
16:00 – 18:00	Contributed talks & Discussion

HI JENA
HELMHOLTZ
Helmholtz-Institut Jena

HZDR
HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

HELMHOLTZ LASER-PLASMA METADATA INITIATIVE (HELPMI)

THRILL

- Initiative: start the development of a data standard for Laser-Plasma-Accelerator experiments
- Adopt NeXus standard from Photon, X-ray and Neutron community
- Extend the openPMD standard and API for arbitrary hierarchies
- Definition and development in close contact with LPA community

Contact: helpmi@hzdr.de
Homepage: https://laser-plasma-metadata.org/
See poster Monday afternoon

This project (ZT-I-PF-3-066) was funded by the Initiative and Networking Fund of the Helmholtz Association in the framework of the Helmholtz Metadata Collaboration project call.

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THANK YOU!

- **End user workshop contributors:** Tommaso Vinci (LULI), Dominik Kraus (Rostock University), Ovidiu TEȘILEANU (ELI-NP), Peter Thirolf (LMU Munich), Andrew Higginbotham (University of York), Florian Wasser (Focused Energy), Laurent Masse (LULI), Joao Santos (CELIA), Nigel Woolsey (University of York), Matt Zepf (Jena University), Eva Los (Imperial College), Frederico Fiuza (SLAC/IST), Carolyn Kuranz (University of Michigan), Arnaud Courvoisier (WIS), Antoine SNIJDERS (LBNL)

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